# The Generation and Propagation of Low Propagation of Low Frequest Vision Hayaves, Naval Research Laboratory Stennis Page Center, USA

PI: James Kaihatu (NRL)
Work supported by NRL Core (ONR)

#### Why low frequency?

- Swells are predominately low frequency
  - Swell requires a wave model
- Shoaling >> relative importance to nearshore operations
- Practical reasons
  - Reduce scope
  - Remove clutter

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#### Potential causes of error

- Numerics and resolution,
- Physical formulations, and
- Wind forcing

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### Propagation Numerics and Resolution

- Tools:
  - Navy Swell Model
  - Navy WAM Cycle 4 Model(s)

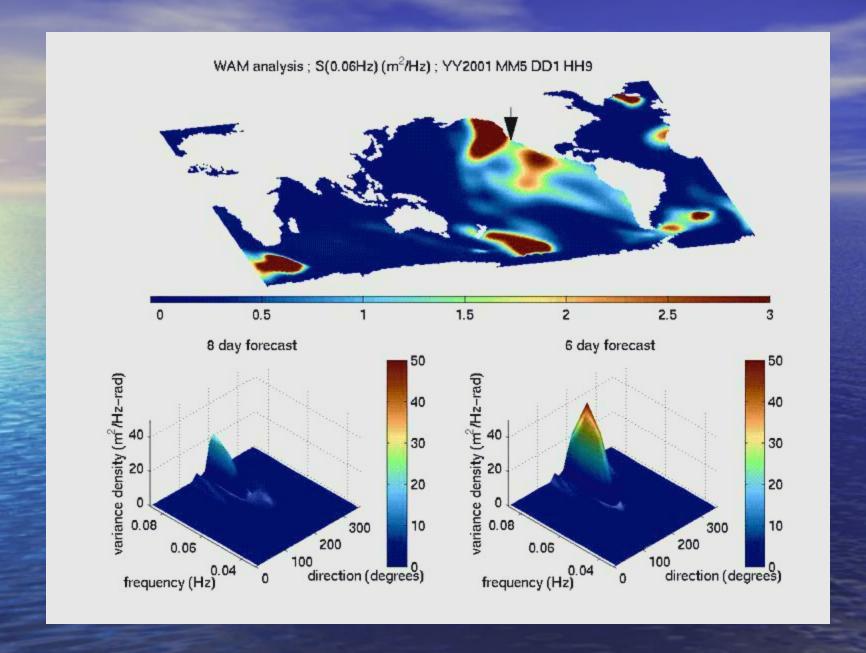
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#### Navy Swell Model (v1)

- O'Reilly (unpublished), Scripps
- Lagrangian (ray-tracing) technique
  - Extremely accurate propagation
    - High resolution (in all dimensions)
    - No diffusion (in any dimension) within model
- Takes energy from WAM4
  - Diffusion in WAM is inherited by swell model
- No internal source/sink terms
- Superb platform for studying effect of numerics

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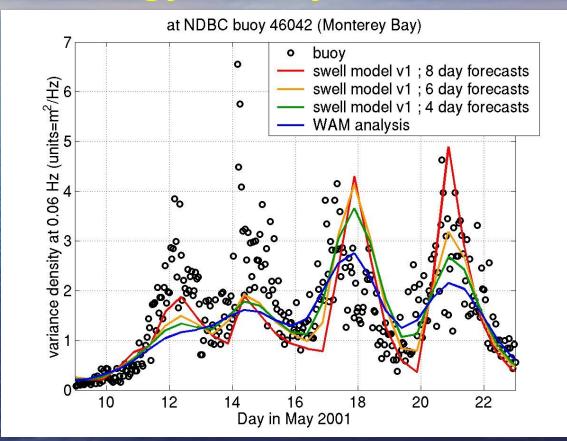
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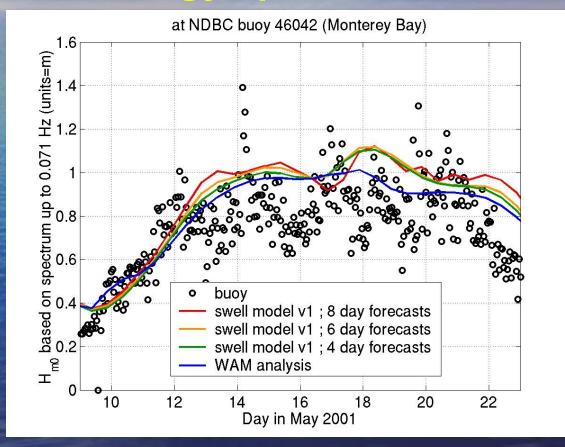
May 13-16,

Waves in Shallo

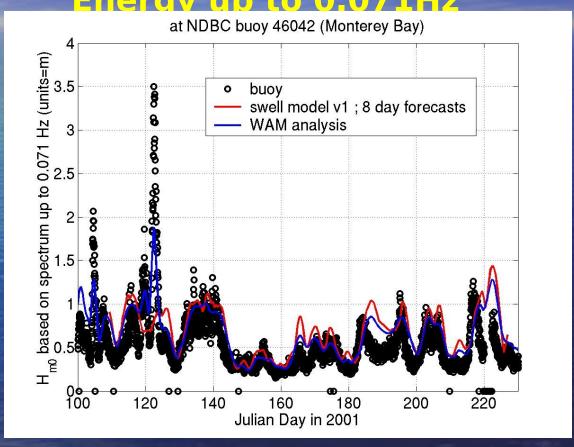
## Navy Swell Model/WAM Time: May 2001 buoy. Energy density at 0.06Hz



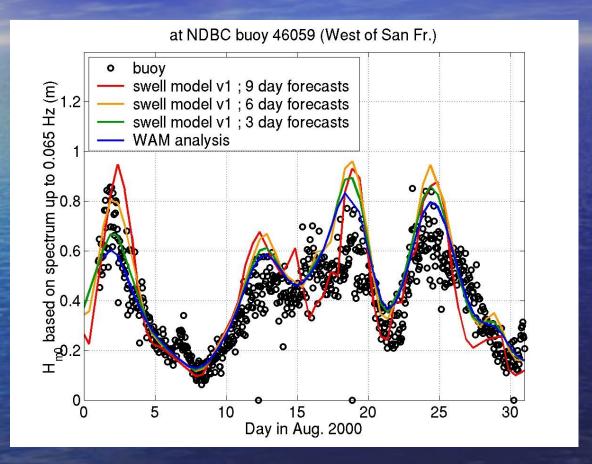
## Navy Swell Model/WAM Time: May 2001 buoy. Energy up to 0.071Hz



### Navy Swell Model/WAM Time: 2001 Location: Monterey buoy. Energy up to 0.071Hz



### Navy Swell Model/WAM Time: Aug. 2000 Location: CA buoy. Energy up to 0.065Hz



(etc....)

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#### Numerics: Summary

- Numerical error in Navy WAM  $H_{m0}$  is typically not large, even for the oldest swells.
  - Diffusion effects tend to be masked if larger frequency range is included in wave height.
  - Diffusion error is often less than nonstationarity of data.
  - Often, numerics are moot.
- Resolution: perhaps only important quite near blocking island groups

#### Remaining causes of error

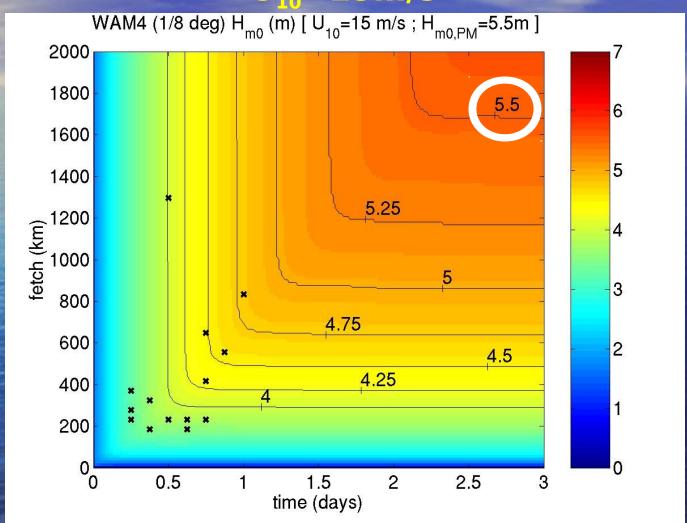
- Physical formulations.
- Wind forcing.

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### Physical Formulation of Wave Models

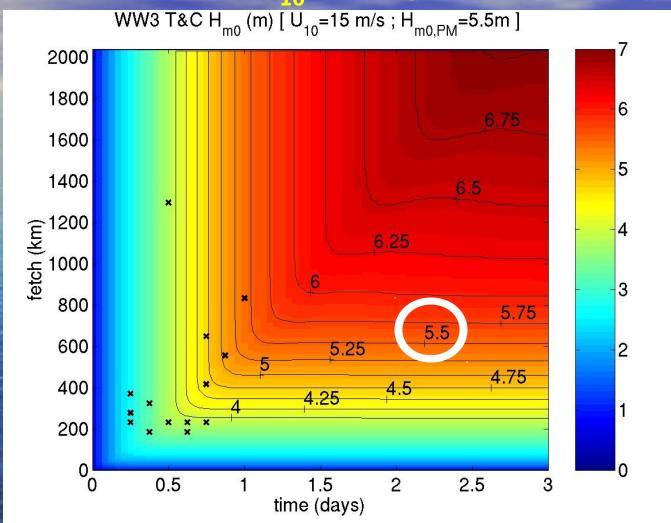
- Canonical cases (growth curves)
  - WAM3, WAM4, WvW3 physics
  - Limited scope.
- Hindcasts vs. buoy data

### Growth Curve, WAM 4 Physics $U_{10}=15$ m/s



Color and contours: model Waves in Shallo X's: Moskowitz 14

### Growth Curve, Tolman and Chalikov Physics $U_{10}=15$ m/s



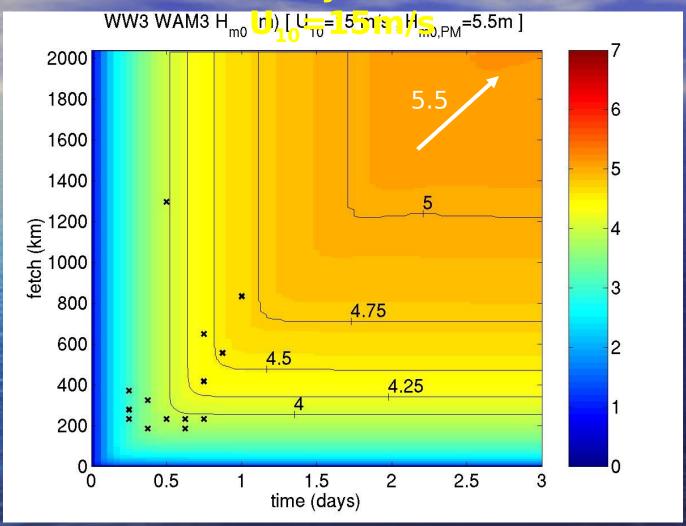
Color and contours: model Waves in Shallo X's: Moskowitz 15

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### Growth Curve, WAM3 (SWAN) Physics



Color and contours: model

Waves in Shallo X's: Moskowitz

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Water Engineer

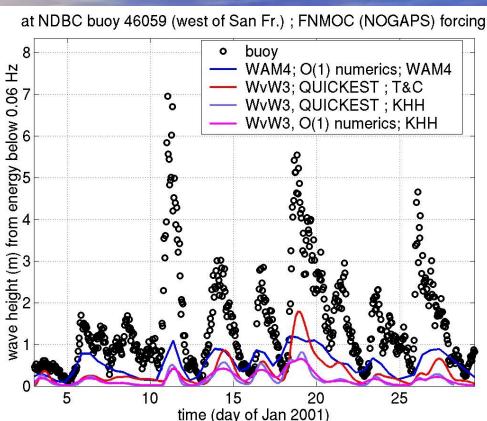
### Canonical cases: conclusions

- Considerable variation between models, though....
- ...The largest differences exist at fetch/durations which are not common in nature.
- Growth curve of WAVEWATCH-III superior, if Moskowitz (1964) taken at face value

# Physical Formulation and Numerics: Relative impact in hindcasts

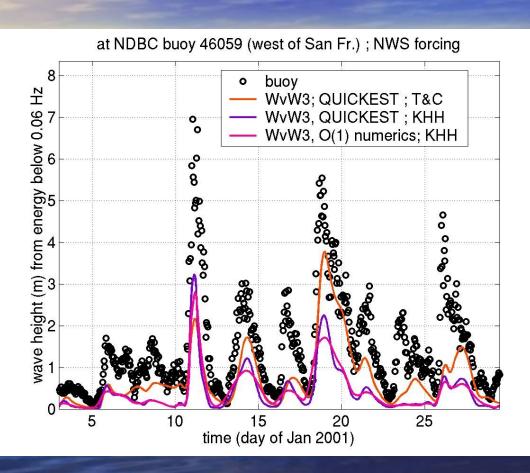
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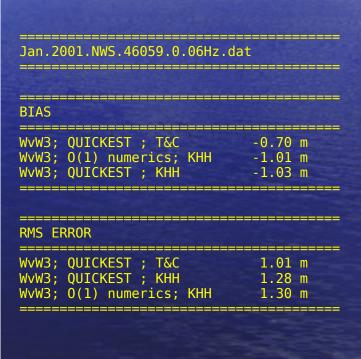
### Time: January 2001. Location: CA buoy. Energy up to 0.06Hz. Simulations with NOGAPS forcing.



Jan.2001.FNMOC.46059	.0.06.dat	
BIAS		
WAM4; O(1) numerics; WvW3; QUICKEST ; T&C	WAM4	-0.88 m -1.20 m
<pre>WvW3; 0(1) numerics; WvW3; QUICKEST ; KHH</pre>	KHH	-1.36 m -1.41 m
RMS ERROR		
WAM4; O(1) numerics; WvW3; QUICKEST ; T&C	WAM4	1.23 m 1.56 m
WvW3; O(1) numerics; WvW3; QUICKEST; KHH	KHH	1.74 m 1.77 m

### Time: January 2001. Location: CA buoy. Energy up to 0.06Hz. Simulations with NWS forcing.





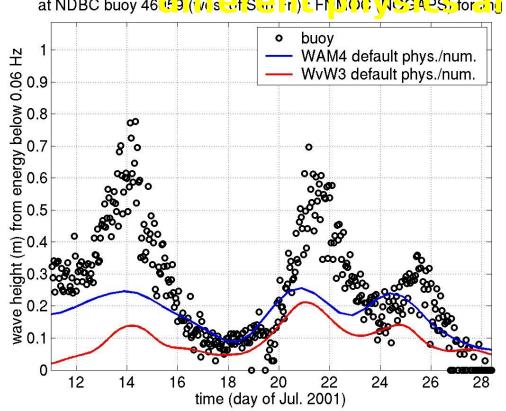
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#### Time: July 2001. buoy.

#### **Location: CA**

### Energy up to 0.06Hz. Simulations with NOGAPS forcing

at NDBC buoy 46 (\$ 9 (1/18 \$ 1 \$ 5 a) 17) EFT NOC YIOS ASS for THE CS.

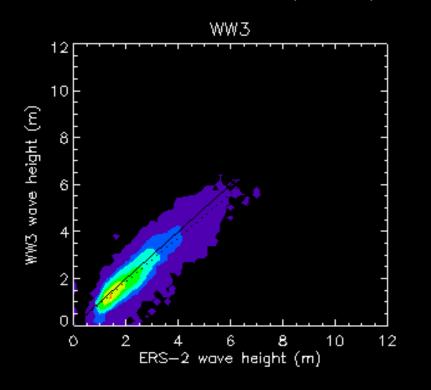


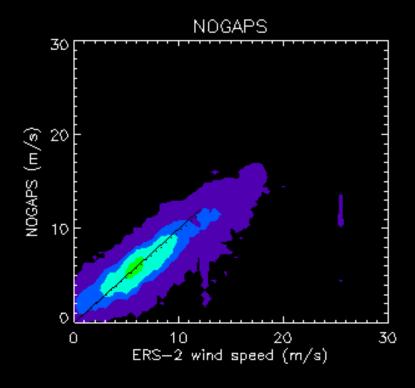
Jul.2001.NOGAPS.46059.0.06	6Hz.dat
BIAS	
WAM4 default phys./num. WvW3 default phys./num.	-0.08 m -0.14 m
RMS ERROR	
WAM4 default phys./num. WvW3 default phys./num.	0.14 m 0.20 m

#### Wind forcing

- Quick regional validation of atmospheric models (FNMOC, NWS).
- Alternative hindcast fields.
- Application of these forcing fields in wave hindcasts.

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WW3/ERS-2 Error Statistics Number of observations: 29705

Bias:-0.16 RMSE: 0.5B Scatter: 0.23 Cor Coef: 0.89

Symetric Slope: 0.93

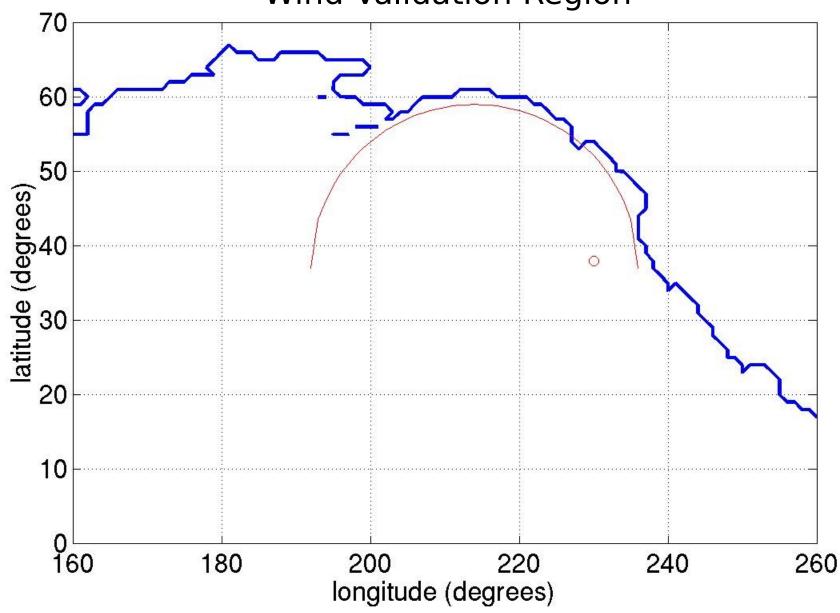
NOGAPS/ERS-2 Error Statistics Number of observations: 24273

Bias:-0.18 RMSE: 1.75 Scatter: 0.28 Cor Coef: 0.77 Symetric Slope: 0.97

(Global)

Figure provided by Dr. Tim Hogan, NRL-Monterey

#### Wind Validation Region



### Wind Validation: NOGAPS model

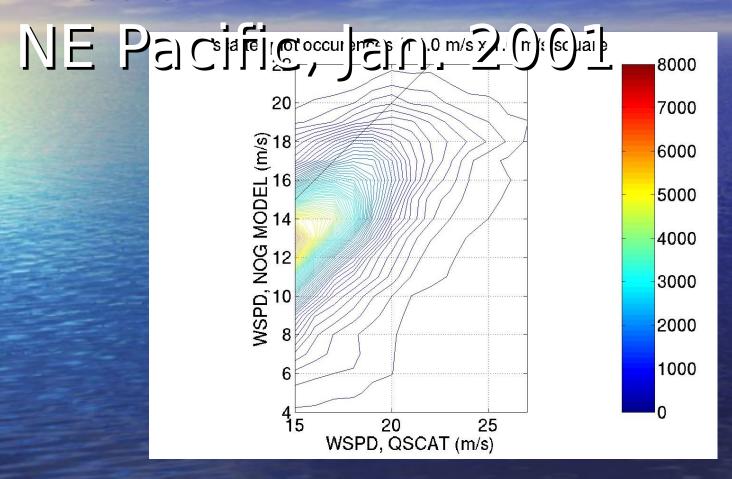
NE Pacific Couls in Com/s 2.0 s Qual WSPD, NOG MODEL (m/s) WSPD, QSCAT (m/s)

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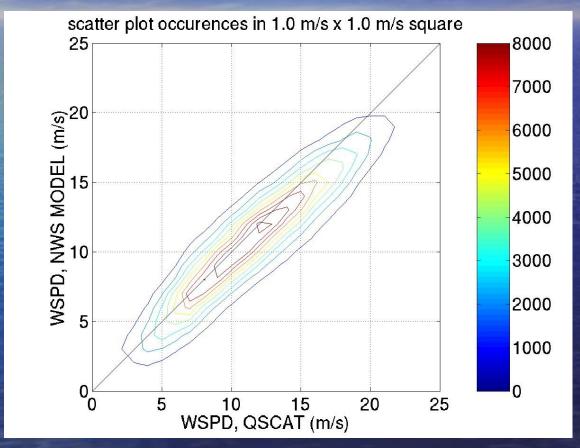
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### Wind Validation: NOGAPS model



### Wind Validation: NWS model NE Pacific, Jan. 2001

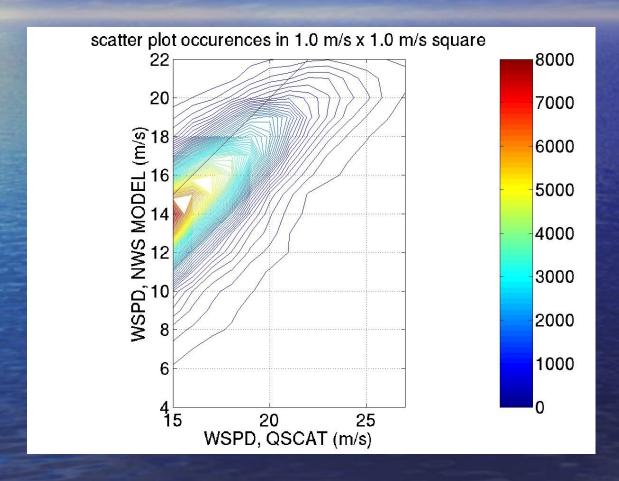


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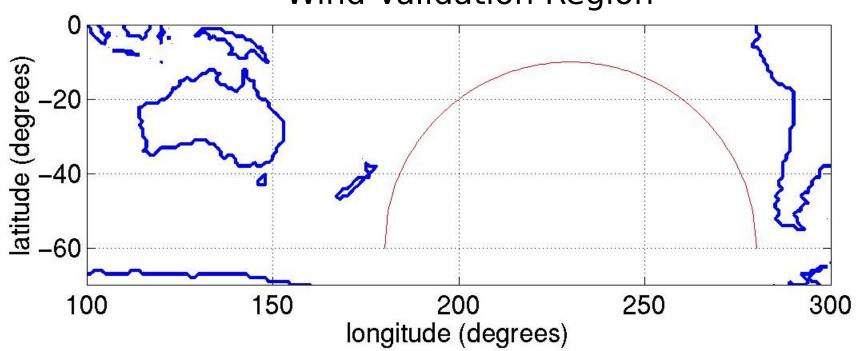
### Wind Validation: NWS model NE Pacific, Jan. 2001



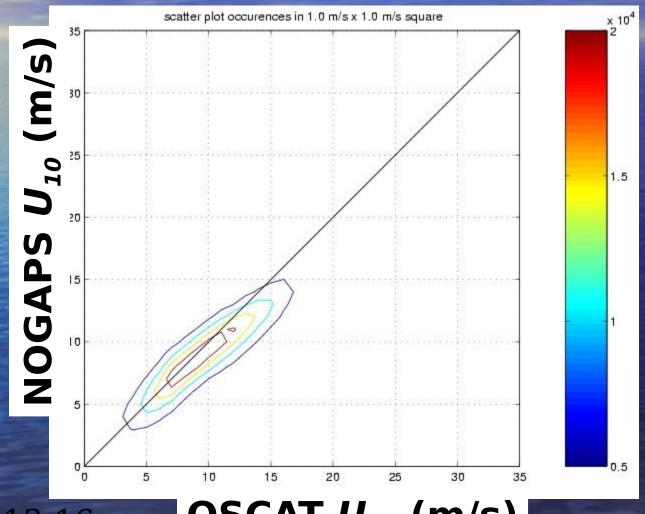
May 13-16,

Waves in Shallo

#### Wind Validation Region



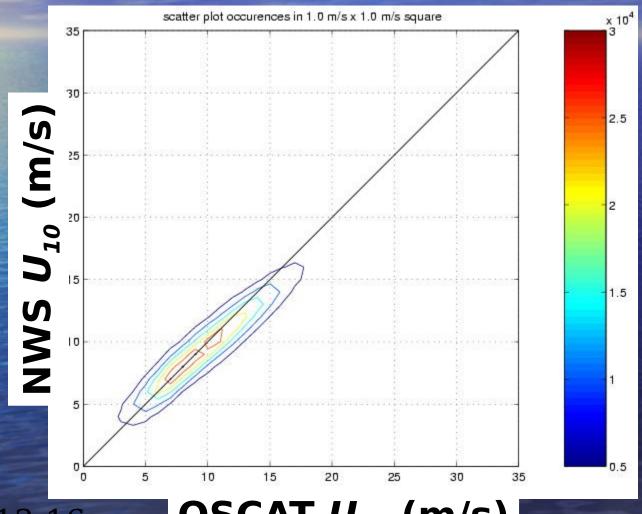
### Southern Ocean: NOGAPS validation



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QSCAT  $U_{10}$  (m/s)

### Southern Ocean: NWS model validation



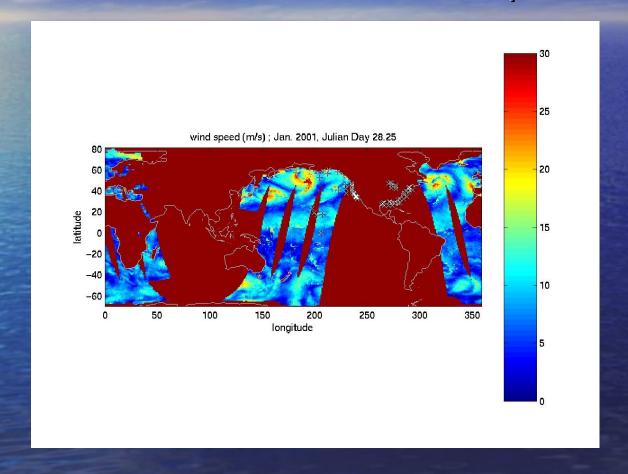
May 13-16,

QSCAT  $U_{10}$  (m/s)

### Alternative to NOGAPS/NWS models: Using wind data in hindcasts

- L2B QuikSCAT data from Jet Prop. Lab.
  - (I also looked at JPL L3 and FSU COAPS)
- Data used when "current", NOGAPS used to fill in other areas
- Question: how aggressively to use the data?
  - (depends on how good (bad) the atmospheric model is)

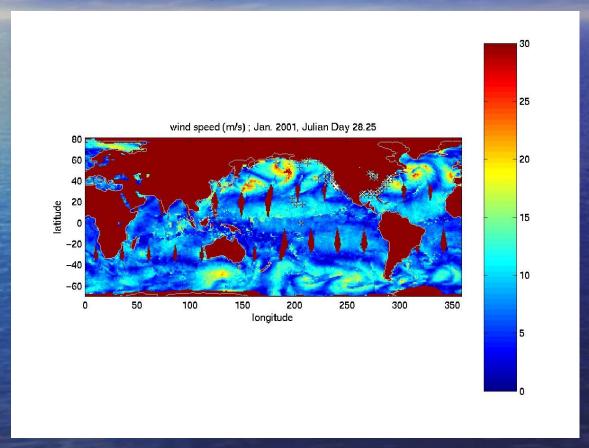
# Creating a "snapshot" field from L2B QuikSCAT data: 6 hour window (within 3 hours prior/after)



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# L2B QuikSCAT data: 24 hour window (within 12 hours prior/after)

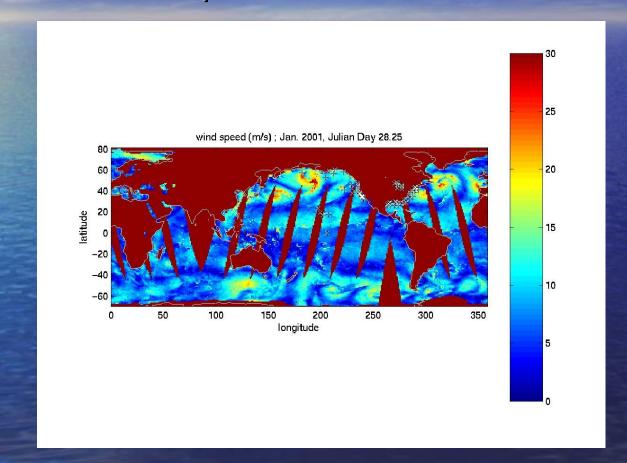


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# L2B QuikSCAT data: 12 hour window (within 6 hours prior/after)



(This one was chosen. NOGAPS used to fill in gaps)

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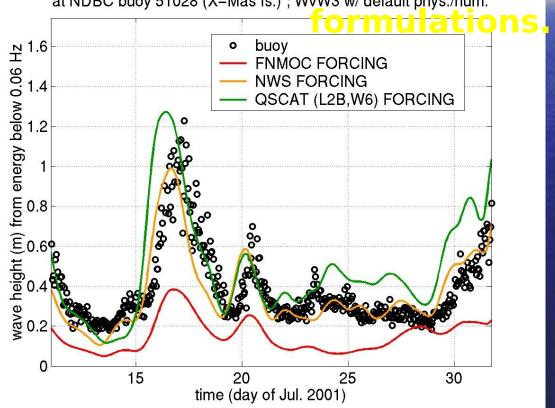
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#### 2001. Time: July Equatorial buoy.

Energy up to 0.06Hz.

Simulations w/ identical physical





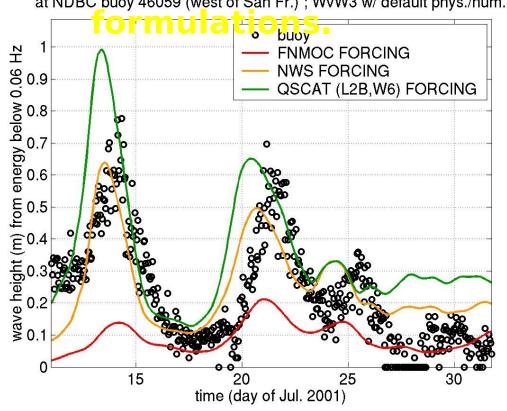
Jul.2001.QTC.51028.0.06Hz.dat			
BIAS			
NWS FORCING QSCAT (L2B,W6) FORCING FNMOC FORCING	-0.02 m 0.10 m -0.23 m		
RMS ERROR			
NWS FORCING QSCAT (L2B,W6) FORCING FNMOC FORCING	0.12 m 0.20 m 0.27 m		

**Location:** 

#### **Location: CA**

Energy up to 0.06Hz. Simulations w/identical physical

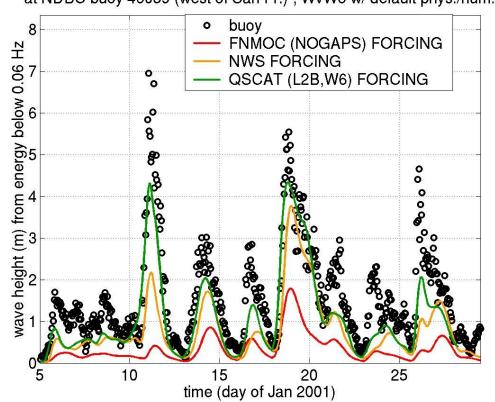
at NDBC buoy 46059 (west of San Fr.); WvW3 w/ default phys./num.



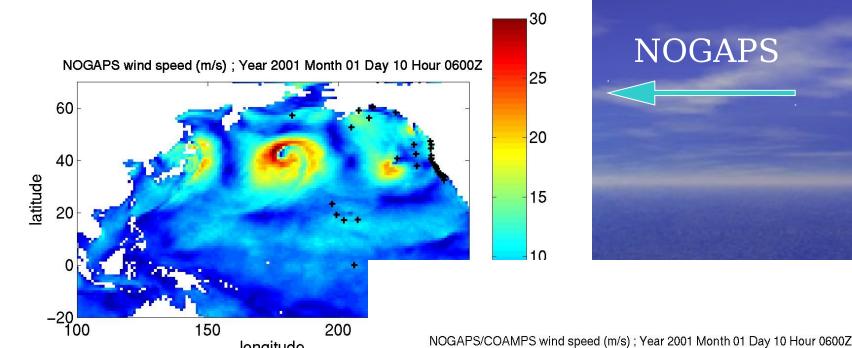
Jul.2001.QTC.46059.0.06Hz.dat		
BIAS		
NWS FORCING QSCAT (L2B,W6) FORCING FNMOC FORCING	0.03 m 0.13 m -0.14 m	
RMS ERROR		
NWS FORCING QSCAT (L2B,W6) FORCING FNMOC FORCING	0.13 m 0.20 m 0.20 m	

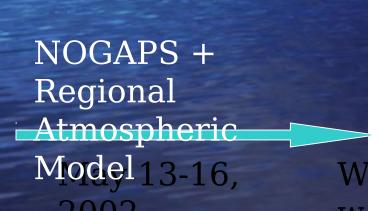
# Time: January 2001. Location: CA buoy. Energy up to 0.06Hz. Simulations w/ identical physical



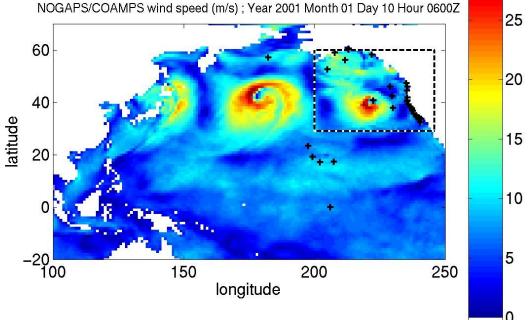


Jan.2001.QTC2.46059.0.06Hz.dat		
BIAS		
QSCAT (L2B,W6) FORCI NWS FORCING FNMOC (NOGAPS) FORCI	-0.70 m	
======================================		
QSCAT (L2B,W6) FORCI NWS FORCING FNMOC (NOGAPS) FORCI	1.01 m	



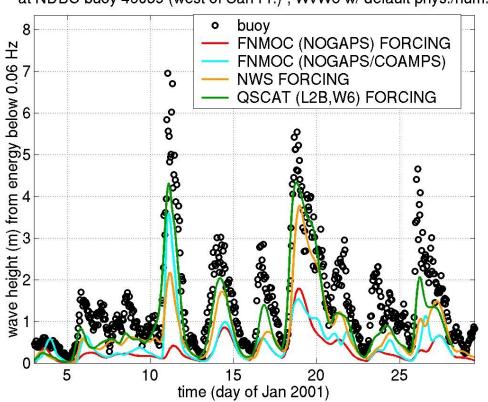


longitude



# Time: January 2001. Location: CA buoy. Energy up to 0.06Hz. Simulations w/ identical physical

at NDBC buoy 46059 (west of San Fr.) ; WvW3 w/ default phys./num.



Jan.2001.QTC.46059.0.06Hz.dat	
BIAS	
QSCAT (L2B,W6) FORCING NWS FORCING FNMOC (NOGAPS/COAMPS) FNMOC (NOGAPS) FORCING	-0.49 m -0.70 m -1.07 m -1.20 m
RMS ERROR	==========
QSCAT (L2B,W6) FORCING NWS FORCING FNMOC (NOGAPS/COAMPS) FNMOC (NOGAPS) FORCING	0.72 m 1.01 m 1.34 m 1.56 m

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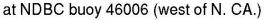
# Wind forcing, Physical Formulation, Numerics, (pretty much everything)

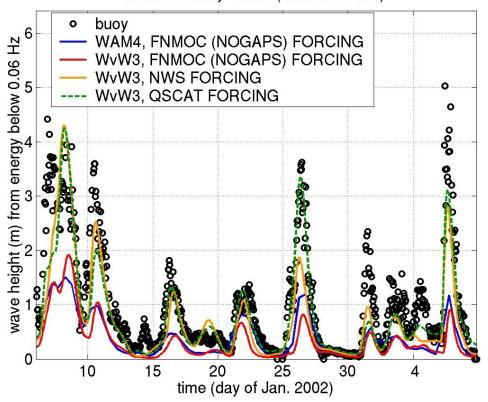
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### Time: Jan./Feb. 2002. CA buoy.

**Location: N.** 

Enorgy up to 0 06Hz.



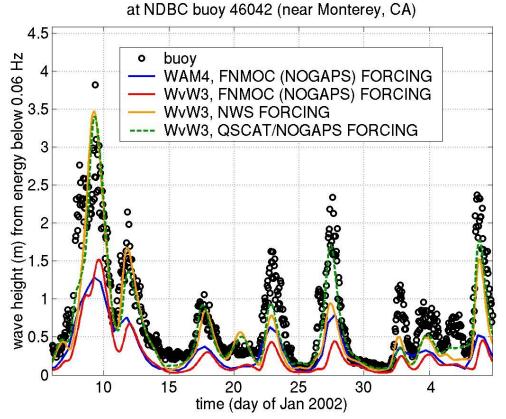


Jan.2002.all.46006.0.06.dat	
BIAS	
WvW3, QSCAT FORCING (L2W6)	-0.19 r
WvW3, NWS FORCING (QTC)	-0.28 r
WAM4, FNMOC (NOGAPS) FORCING	-0.59 r
WvW3, FNMOC (NOGAPS) FORCING	-0.67 r
RMS ERROR	
WAR OSCAT FORCING (LOWE)	0.51 r
WvW3, QSCAT FORCING (L2W6) WvW3, NWS FORCING (QTC)	0.51 i
WAM4, FNMOC (NOGAPS) FORCING	0.50 i
WVW3, FNMOC (NOGAPS) FORCING	0.92 r
======================================	0.96

### Time: Jan./Feb. 2002. Monterey buoy.

#### **Location:**





Jan.2002.all.46042.0.06Hz.dat	
BIAS	
WvW3, QSCAT/NOGAPS FORCING WvW3, NWS FORCING WAM4, FNMOC (NOGAPS) FORCING WvW3, FNMOC (NOGAPS) FORCING	-0.14 m -0.20 m -0.40 m -0.50 m
RMS ERROR	
WvW3, QSCAT/NOGAPS FORCING WvW3, NWS FORCING WAM4, FNMOC (NOGAPS) FORCING WvW3, FNMOC (NOGAPS) FORCING	0.31 m 0.39 m 0.54 m 0.65 m

### Open Issues

- NAVO WAM4 with accurate winds?
- Quantify impact of resolution of topography (in wave model).
- Include other scatterometers
- Smooth transition in "blended" fields (e.g. weighting function based on time)

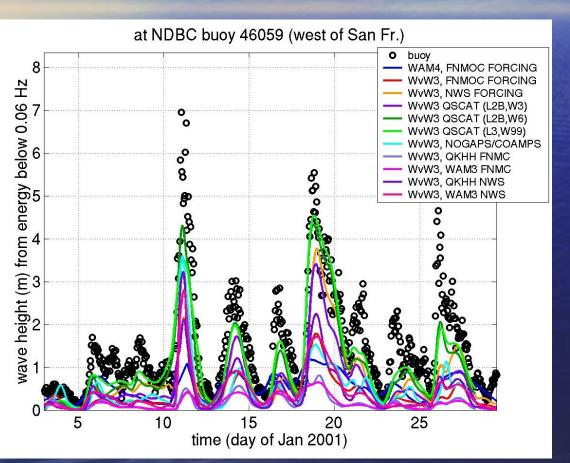
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### Conclusions (context: the Navy's global wave models)

- Accuracy of models is limited by present wind forcing (high wind speed; surface winds).
- Propagations numerics, resolution important but not (yet!) 1st order error (even w/WAM).
- Physical formulations (WAM4, WvW3) have a small but measurable impact.
- Scatterometer data can be utilized more than they are now.



### Time: January 2001. Location: CA buoy. Energy up to 0.06Hz. All simulations.



Jan.2001.all.46059.0.06Hz.dat

BIAS	
WvW3 QSCAT (L3,W99)	-0.38 m
WvW3 QSCAT (L2B,W6)	-0.49 m
WvW3 NWS FORCING	-0.70 m
WAM4 FNMOC FORCING	-0.88 m
WvW3 QSCAT (L2B,W3)	-0.91 m
WvW3 WAM3 NWS	-1.01 m
WvW3 QKHH NWS	-1.03 m
WvW3 NOGAPS/COAMPS	-1.07 m
WvW3 FNMOC FORCING	-1.20 m
WvW3 WAM3 FNMC	-1.36 m
WvW3 QKHH FNMC	-1.41 m

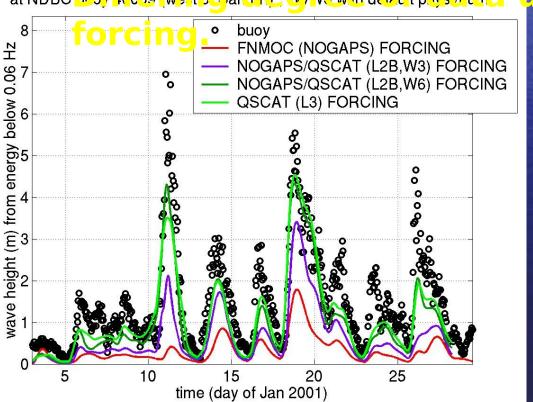
RMS ERRUR		
WvW3 QSCAT (L3,W99)	0.69 m	
WvW3 QSCAT (L2B,W6)	0.72 m	
WvW3 NWS FORCING	1.01 m	
WvW3 QSCAT (L2B,W3)	1.18 m	
WAM4 FNMOC FORCING	1.23 m	
WvW3 QKHH NWS	1.28 m	
WvW3 WAM3 NWS	1.30 m	
WvW3 NOGAPS/COAMPS	1.34 m	
WvW3 FNMOC FORCING	1.56 m	
WvW3 WAM3 FNMC	1.74 m	
WvW3 QKHH FNMC	1.77 m	

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# Time: January 2001. Location: CA buoy. Energy up to 0.06Hz. Simulations w/ identical physical formulations.

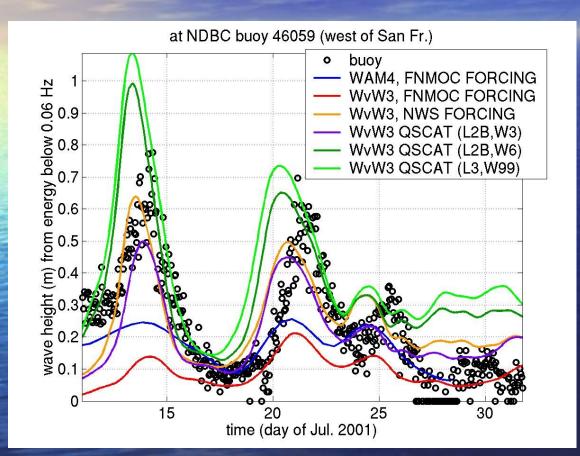
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Jan.2001.QSC.46059.0.06Hz.dat	
BIAS	
QSCAT (L3) FORCING	-0.38
NOGAPS/QSCAT (L2B,W6) FORCING	-0.49
NOGAPS/QSCAT (L2B,W3) FORCING	-0.91
FNMOC (NOGAPS) FORCING	-1.20
RMS ERROR	
OSCAT (L3) FORCING	 0.69
NOGAPS/OSCAT (L2B,W6) FORCING	0.72
NOGAPS/QSCAT (L2B,W3) FORCING	1.18
FNMOC (NOGAPS) FORCING	1.56

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# Time: July 2001. Location: CA buoy. Energy up to 0.06Hz. All simulations.

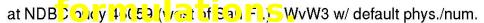


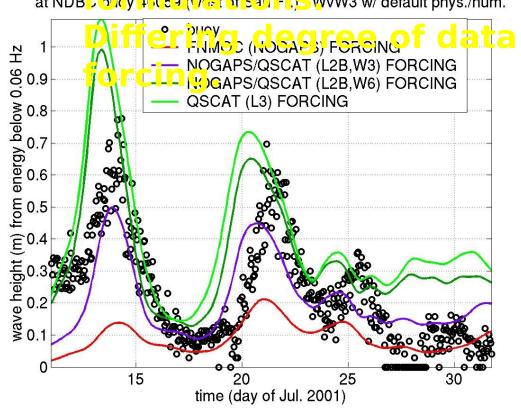
Jul.2001.all.46059.0.06Hz.dat		
BIAS		
WvW3, QSCAT (L2B,W3) WvW3, NWS FORCING WAM4, FNMOC FORCING WvW3, QSCAT (L2B,W6) WvW3, FNMOC FORCING WvW3, QSCAT (L3,W99)	-0.01 m 0.03 m -0.08 m 0.13 m -0.14 m 0.19 m	
RMS ERROR		
WvW3, QSCAT (L2B,W3) WvW3, NWS FORCING WAM4, FNMOC FORCING WvW3, QSCAT (L2B,W6) WvW3, FNMOC FORCING WvW3, QSCAT (L3,W99)	0.12 m 0.13 m 0.14 m 0.20 m 0.20 m 0.25 m	

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#### **Location: CA**

## Energy up to 0.06Hz. Simulations w/ identical physical





#### usage in wind

Jul.2001.QSC.46059.0.06Hz.dat

#### BIAS

NOGAPS/QSCAT (L2B,W3) FORCING	-0.01 r
NOGAPS/QSCAT (L2B, W6) FORCING	0.13 r
FNMOC (NOGAPS) FORCING	-0.14 r
OCCAT (L2) FORCTMC	0 10 -

SCAI (LS) FURCING U.19 N

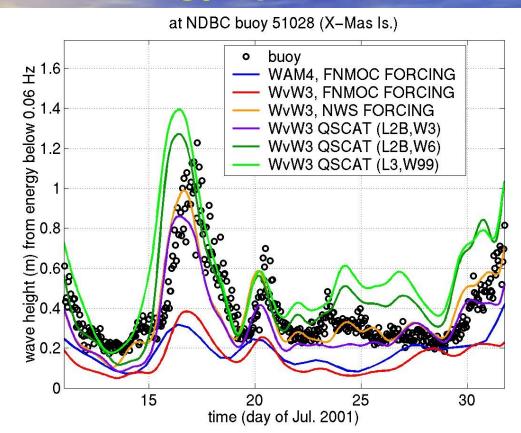
#### RMS FRROR

NOGAPS/QSCAT (L2B,W3) FORCING	0.12 m
NOGAPS/QSCAT (L2B,W6) FORCING	0.20 m
FNMOC (NOGAPS) FORCING	0.20 m
QSCAT (L3) FORCING	0.25 m

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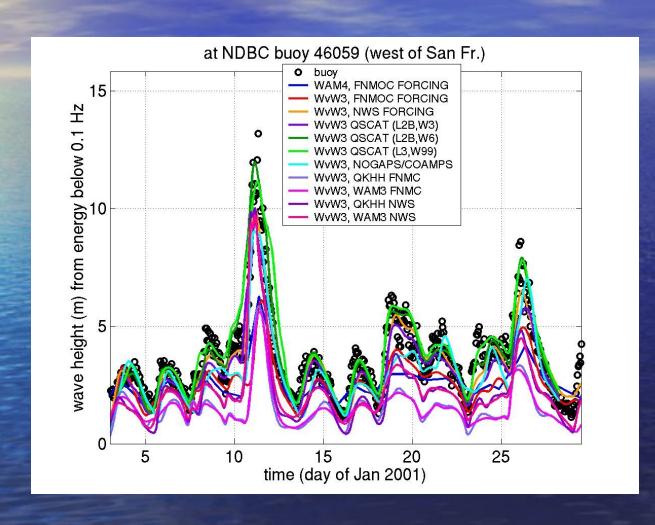
Waves in Shallo

# Time: July 2001. Location: Equatorial buoy. Energy up to 0.06Hz. All simulations.



Jul.2001.all.51028.0.06Hz.dat		
BIAS		
WvW3, NWS FORCING WvW3, QSCAT (L2B,W3) WvW3, QSCAT (L2B,W6) WvW3, QSCAT (L3,W99) WvW3, FNMOC FORCING WAM4, FNMOC FORCING	-0.02 m -0.07 m 0.10 m 0.18 m -0.23 m -0.23 m	
RMS ERROR		
WvW3, NWS FORCING WvW3, QSCAT (L2B,W3) WvW3, QSCAT (L2B,W6) WvW3, QSCAT (L3,W99) WvW3, FNMOC FORCING WAM4, FNMOC FORCING	0.12 m 0.14 m 0.20 m 0.26 m 0.27 m 0.30 m	

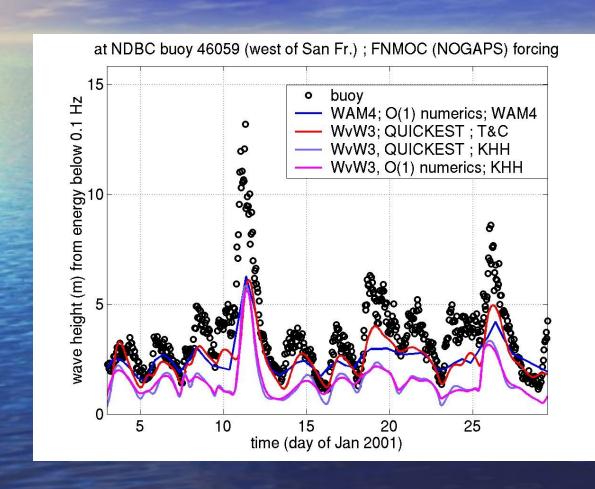
### Time: January 2001. Location: CA buoy. Energy up to 0.10Hz. All simulations.



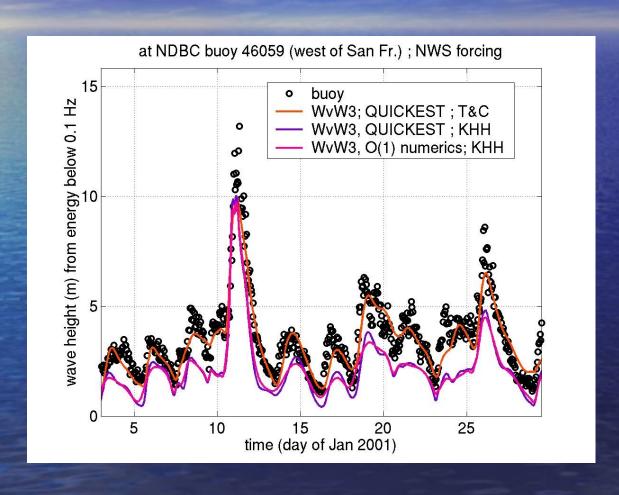
May 13-16,

Waves in Shallo

# Time: January 2001. Location: CA buoy. Energy up to 0.10Hz. Simulations with NOGAPS forcing.



# Time: January 2001. Location: CA buoy. Energy up to 0.10Hz. Simulations with NWS forcing.

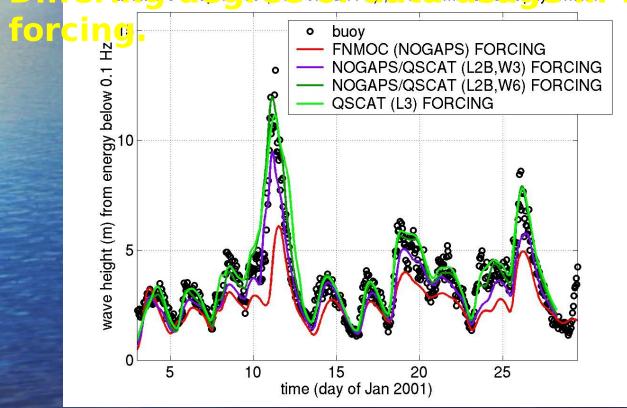


May 13-16,

Waves in Shallo

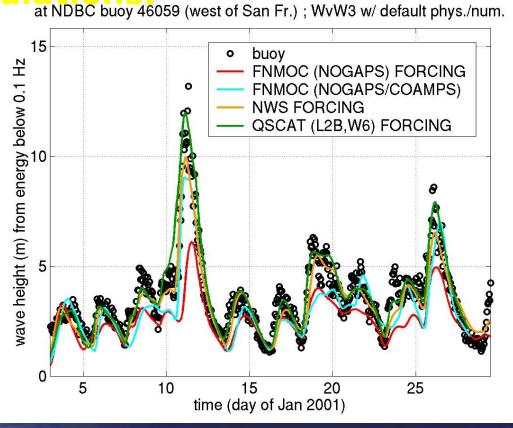
Time: January 2001. Location: CA buoy. Energy up to 0.10Hz. Simulations w/ identical physical formulations.

PIFE Fall@Col@4989@@ofSanFQ;WWowibbecotolgS/nunn VVInd



Time: January 2001. Location: CA buoy. Energy up to 0.10Hz. Simulations w/ identical physical

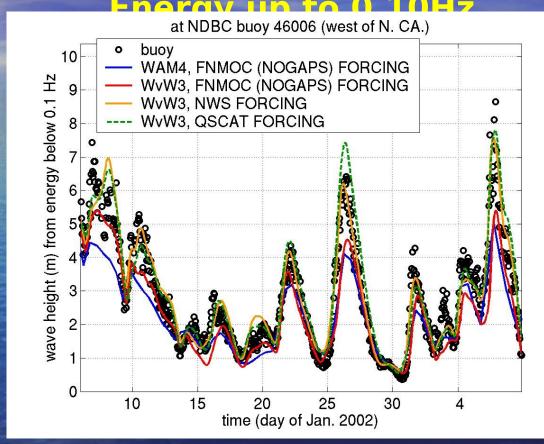




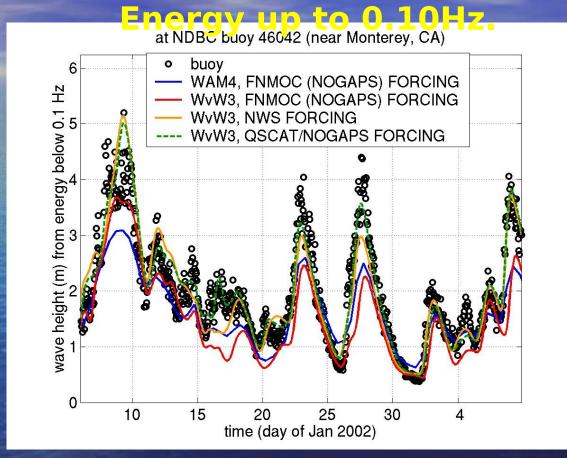
#### Time: Jan./Feb. 2002. CA buoy.

#### Location: N.

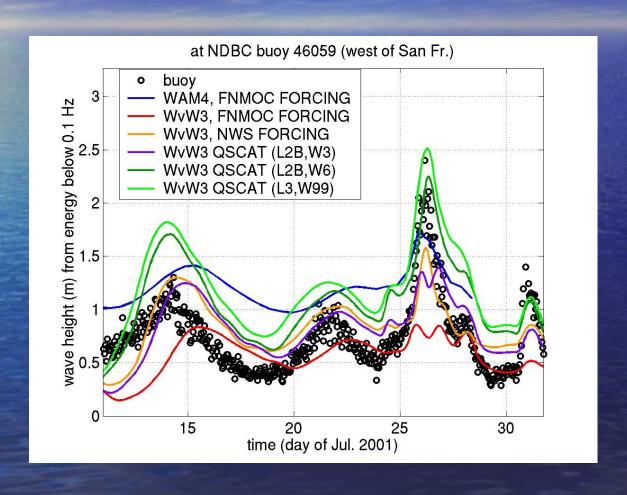




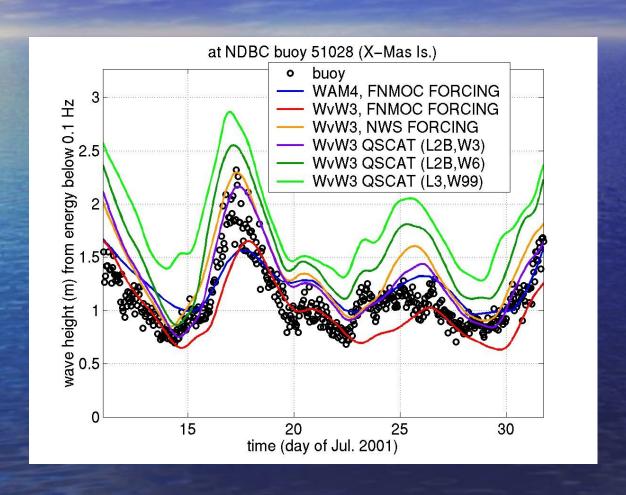
## Time: Jan./Feb. 2002. Location: Monterey buoy.



# Time: July 2001. Location: CA buoy. Energy up to 0.10Hz. All simulations.



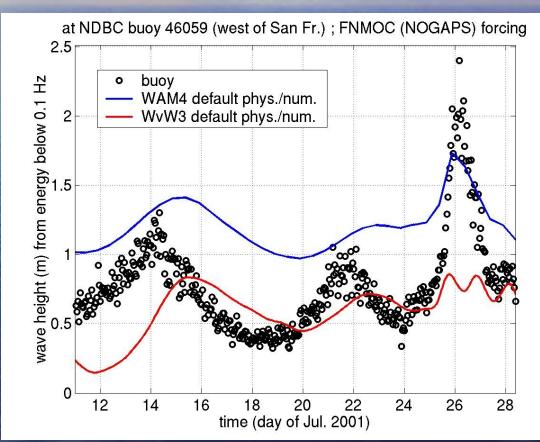
# Time: July 2001. Location: Equatorial buoy. Energy up to 0.10Hz. All simulations.



**Location: CA** 

Energy up to 0.10Hz.

Simulations with NOGAPS forcing.

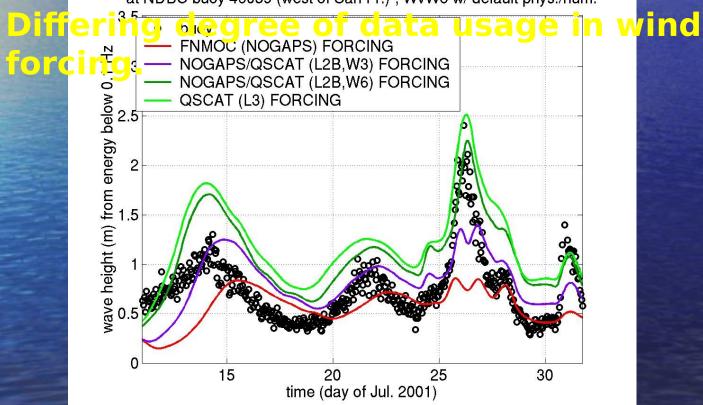


**Location: CA** 

Energy up to 0.10Hz.

Simulations w/ identical physical

at NDBC buoy 45059 (west of San Fr.) ; WvW3 w/ default phys./num.

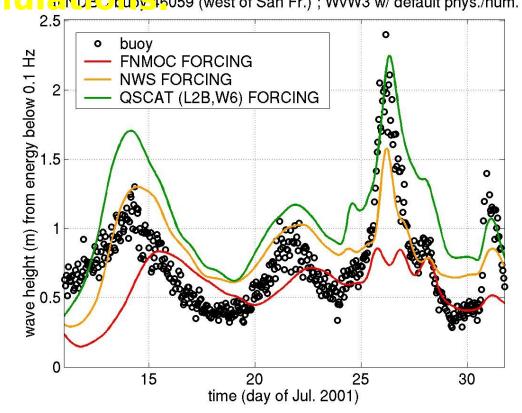


**Location: CA** 

Energy up to 0.10Hz.

Simulations w/ identical physical

MvW3 w/ default phys./num.



Time: July 2001. Equatorial buoy.

#### **Location:**

### Energy up to 0.10Hz. Simulations w/ identical physical

